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THE CORROSION SOCIETY

Standard
Recommended Practice

Corrosion Control of Underground Storage Tank Systems by Cathodic Protection

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Foreword

This standard recommended practice presents procedures and practices for effective control of external corrosion on underground storage tank (UST) systems by cathodic protection (CP). It is intended to be used by competent corrosion professionals as a reference for corrosion control of buried metallic underground storage tanks including those used to contain oil, gas, and water using CP. Specifically addressed is CP of:

(a) Existing bare and coated mild steel tanks;
(b) New coated mild steel tanks;
(c) Metallic piping and flexible connectors; and
(d) Other metallic components.

For accurate and correct application of this standard, this standard must be used in its entirety. Using or referring to only specific paragraphs or sections can lead to misinterpretation and misapplication of the recommendations and practices contained in the standard.

This standard was originally published in 1985 by Task Group T-10A-14 as "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems." The standard was revised in 1995 by Task Group T-10A-14 on Corrosion Control of Underground Storage Tank Systems, a component of Unit Committee T-10A on Cathodic Protection. It was revised in 2001 by TG 011 on Corrosion Control of Underground Storage Tank Systems by Cathodic Protection. Task Group 011 is administered by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings and is sponsored by STG 03 on Protective Coating and Linings—Immersion/Buried and STG 05 on Cathodic/Anodic Protection. This standard is issued by NACE International under the auspices of STG 35 on Pipelines, Tanks, and Well Casings.

In NACE standards, the terms *shall, must, should,* and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state that which is considered good and is recommended but is not absolutely mandatory. *May* is used to state that which is considered optional.

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Standard
Recommended Practice

Corrosion Control of Underground Storage Tanks Systems by Cathodic Protection

Contents

Section 1: General

1.1 Introduction

1.1.1 This standard is intended to serve as a guide for establishing minimum requirements for the control of external corrosion on UST systems that are buried, partially buried, or in contact with the soil.

1.1.2 This standard does not designate specific practices for every situation because the complexity of some environmental conditions in which systems are buried precludes standardization of corrosion control practices.

1.1.3 This standard does not include corrosion control methods based on chemical control of the environment, internal linings, or the use of tank construction materials other than mild steel.

1.1.4 This standard does not override applicable safety codes and should not be used to infringe on the primary requirement of protecting personnel, the environment, and equipment. In any situation, the corrosion protection design for underground structures should incorporate all requirements of any applicable codes, standards, and regulations as determined by authorities having jurisdiction.

1.1.5 The provisions of this standard shall be applied under the responsible direction of competent individuals. Such individuals must either be registered professional engineers, NACE International Certified Corrosion Specialists or CP Specialists, or individuals qualified by professional education and related practical experience. All of the above individuals must be able to demonstrate suitable experience in corrosion control of UST systems.

1.1.6 Deviation from this standard may be warranted in specific situations provided the objectives expressed in this standard have been achieved.

Section 2: Definitions

Anode: The electrode of an electrochemical cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

Cathodic Polarization: The change of the electrode potential in the active (negative) direction caused by current across the electrode/electrolyte interface. (See *Polarization.*)

Cathodic Protection (CP): A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Continuity Bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

Corrosion Potential (E_{corr}): The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions (also known as *rest potential, open-circuit potential,* or *freely corroding potential*).

Current Density: The current to or from a unit area of an electrode surface.

Dielectric Coating: A coating that does not conduct electricity.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrochemical Cell: A system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit. The anode and cathode may be different metals or dissimilar areas on the same metal surface.

Electrode Potential: The potential of an electrode in an electrolyte as measured against a reference electrode. (The electrode potential does not include any resistance losses in potential in either the solution or the external circuit. It represents the reversible work to move a unit of charge from the electrode surface through the electrolyte to the reference electrode.)

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purposes of this standard, electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic UST system, including the moisture and other chemicals contained therein.

Electrolytic Corrosion: Corrosion caused by an external source of direct current.

Foreign Structure: Any metallic structure that is not intended as part of a system under CP.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of CP.

Galvanic Series: A list of metals and alloys arranged according to their corrosion potentials in a given environment.

Groundbed: One or more anodes installed below the earth's surface for the purpose of supplying CP.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for CP.)

Insulating Coating System: All components comprising the protective coating, the sum of which provides effective electrical isolation of the coated structure.

Interference Bond: A metallic connection designed to control electrical current interchange between metallic systems.

IR Drop: The voltage across a resistance in accordance with Ohm's Law.

Isolation: See *Electrical Isolation.*

Net Driving Potential: The difference between the cathode potential and the anode potential in a galvanic circuit.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface. In this standard, polarization is considered to be the change of potential of a metal surface resulting from the passage of current directly to or from an electrode.

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Potential Gradient: A change in the potential with respect to distance, expressed in millivolts per unit of distance.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Stray Current: Current through paths other than the intended circuit.

Stray-Current Corrosion: Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth.

Structure-to-Electrolyte Potential (also structure-to-soil potential or pipe-to-soil potential): The potential difference between a buried metallic structure and the electrolyte that is measured with a reference electrode in contact with the electrolyte.

Structure-to-Structure Potential: The difference in voltage between metallic structures in a common electrolyte.

Tank-to-Soil Potential (also tank-to-electrolyte potential): The potential difference between the tank metallic surface and the electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Underground Storage Tank (UST) System: The equipment and facility constructed, maintained, or used for underground storage of products including tanks, piping, pumps, and appurtenances associated with filling, storage, and dispensing of the stored products.

Section 3: Cathodic Protection of New UST Systems

3.1 General

3.1.1 There are three basic types of CP available for new UST systems:

(a) Factory-fabricated galvanic anode systems.
(b) Field-installed galvanic anode systems.
(c) Field-installed impressed current systems.

3.1.2 The recommended practices with respect to field-installed systems are similar to those for existing UST systems described in Section 4.

3.2 Factory-Fabricated CP Systems

3.2.1 Single- and Double-Wall Tanks

3.2.1.1 Factory-fabricated galvanic anode CP systems are available for new USTs. The design and specifications for the factory-fabricated galvanic anode CP systems consider three important factors:

(a) the galvanic anodes;
(b) a dielectric coating; and
(c) electrical isolation.

The components are designed together as a system to achieve corrosion protection for various tank sizes and most site conditions. Bonding of this system to other structures may violate the manufacturer's warranty.

3.2.2 Anodes

3.2.2.1 Packaged zinc or magnesium anodes are used for factory-fabricated systems. Aluminum anodes usually are not effective in underground applications. The size and number of anodes required to protect a tank from corrosion is predetermined by calculations based on the desired design life, the tank surface area, the quality of the coating, anode type, anode size, and the range of soil resistivity in which it is anticipated that the tank will be installed.

3.2.2.2 The anodes can be attached directly to the tank or wired through a test station to the tank. The type of anode used is determined by site conditions and operational factors. Zinc is the most common type of anode used for factory-fabricated systems. Magnesium anodes are more effective in high soil resistivities and shall be used on tanks where the anode temperature exceeds 49°C (120°F).

3.3 Piping for New USTs

3.3.1 Corrosion protection of all underground piping associated with the UST system can be achieved through a combination of material selection, system design, and coatings.

3.3.2 Piping within a secondary containment piping system may require other corrosion control methods in lieu of CP.

3.3.3 Several design parameters to be considered in selecting materials include:

(a) compatibility with the environment;
(b) compatibility with the product to be contained; and
(c) pressure and temperature.

3.3.4 Metallic Piping

3.3.4.1 Metallic piping in contact with an electrolyte shall be protected from external corrosion through the application of coatings and CP.

3.3.4.2 When available, factory-applied coatings are preferred. The following NACE International standards may be helpful:

(a) RP0190;[1]
(b) RP0185;[2]
(c) RP0375;[3] and
(d) MR0274.[4]

3.3.4.3 All metallic components to be cathodically protected should be made electrically continuous. When using galvanic anode CP, all metallic components to be protected should be electrically isolated from all other metallic components.

3.3.4.4 Metal piping with mechanical joints may require bonding to ensure electrical continuity.

3.3.4.5 Recommendations for CP monitoring, including facilities and configurations, are given in Section 8.

3.3.4.6 Metallic secondary containment systems exposed to an electrolyte should be cathodically protected.

3.3.4.7 CP systems shall be designed to mitigate any adverse effects from stray current on foreign metallic structures within the influence of the CP system.

3.3.5 Nonmetallic Piping

3.3.5.1 Nonmetallic piping cannot be protected by CP; however, any metallic components of the product piping system that are exposed to soil shall be protected.

3.3.5.2 Materials selection should assure product compatibility not only with the basic pipe material, but also with any adhesives or joint compounds.

3.3.6 Flexible Connectors

3.3.6.1 Flexible connectors are used on rigid piping systems to accommodate pipe movement. These connections, depending on materials of construction, may create dissimilar metal couples in buried applications.

3.3.6.2 Flexible connectors may not provide electrical continuity. Verification and bonding may be required based on the system design.

3.3.6.3 All metallic components of the connection in contact with the electrolyte shall be cathodically protected. (Protection of flexible connectors is often overlooked in nonmetallic piping systems.)

3.3.6.4 Factory-fabricated CP systems are available for flexible connectors.

3.3.7 All corrosion protection systems should be monitored in accordance with Section 8 on Operation and Maintenance.

3.4 Coatings

3.4.1 A high-quality dielectric coating should be applied to a properly prepared surface of the exterior areas of the UST including anode connections, attachments, and lifting lugs. Crevice or corner areas that restrict coating coverage should be seal welded prior to coating.

3.4.2 Any type of coating used on a steel tank must have high dielectric properties. The purpose of a dielectric coating is to isolate the tanks electrically from the environment while reducing demands on the CP system. Other properties necessary in a dielectric coating are resistance to environmental fluids and the product being stored, impact/abrasion resistance, adhesion, and resistance to cathodic disbondment.

3.4.2.1 Three types of dielectric coatings commonly used on steel USTs are polyurethanes, epoxies, and reinforced plastics. Performance of these coatings should conform to a recognized industry standard such as:

(a) STI[(1)] T871,[5] or
(b) UL[(2)]1746,[6] Part 1, Section 10.

3.4.2.2 When flaws, damage, and degradation occur on coatings, these damaged areas must be repaired in accordance with manufacturer's specifications.

3.5 Electrical Isolation

3.5.1 A factory-fabricated cathodically protected steel tank is usually electrically isolated from all other structures (product and vent piping, hold-down straps, liquid-level monitoring systems, interstitial space monitors, conduit lines, etc.) for the CP system to perform as designed. Electrical isolation of a factory-fabricated cathodically protected UST is required because the CP system design capacity is sufficient only for the tank. Isolation devices are normally installed at the manufacturing plant to eliminate installation errors and to be compatible with the product being stored. The device used to ensure isolation is dependent on the type of connection being made to the tank. Electrical isolation devices should only be used within their temperature and pressure limitations.

3.5.1.1 Dielectric bushings are used for threaded connections in nonpressure tanks. These bushings shall be as specified in UL Standard 1746, Part I, Section 11, and STI-P3,[7] or meet equivalent requirements.

3.5.1.2 Flanged connections are used when conditions preclude the use of dielectric bushings. Flange isolation kits should be used if flanged connections are to be made in the field.

3.5.1.3 If hold-down straps are to be used, effective isolation material shall be used between the strap and tank surface.

3.5.2 The isolation should be verified after installation is completed but before backfilling and final paving or grading.

3.6 Backfill Requirements

3.6.1 The backfill shall be a homogeneous material that is compatible with the coating and CP system. The backfill material shall be free of large rocks, trash, debris, ice, and other nonhomogeneous materials.

3.6.2 The CP design shall consider situations in which protective current flow is obstructed by geologic conditions or the presence of other structures.

3.7 Miscellaneous

3.7.1 Tanks are often anchored to prevent buoyant forces from floating the tanks. Anchor materials shall consist of flat straps that are isolated from the tank surface with a dielectric insulating material. Wire cable or steel round bars should not be used because point-of-contact damage to the coating can occur. Corrosion control of the strap components shall be considered.

3.7.2 Each protected UST system should have the following:

(a) a dedicated test lead wire connected to the structure;
(b) access to the electrolyte for portable reference electrode tests; and
(c) accessible connection points for all permanently installed monitoring devices.

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(1) Steel Tank Institute (STI), 570 Oakwood Rd., Lake Zurich, IL 60047.
(2) Underwriters Laboratories Inc. (UL), 333 Pfingsten Rd., Northbrook, IL 60062.

Section 4: Cathodic Protection of Existing UST Systems

4.1 Prior to initiation of the field testing necessary for design of CP, it is advisable to assemble information concerning the history of the tank(s) to be protected. This information generally falls into two groups: physical description and operating history. Although all information may not be available for every tank, it is important to obtain as much as possible. This information can save field investigation time, resulting in a more cost-effective system, and can help to avoid an ineffective design.

4.2 Physical Description

4.2.1 Size, Configuration, and Condition: The type of CP system and the amount of cathodic current required to protect the tanks and piping depends on the surface area, coating quality of the structures, and the properties of the electrolyte. The configuration of the tanks and piping and their location with respect to other structures at the site may also affect the type of system selected.

4.2.2 Materials of Construction: Knowledge of the materials and construction of the tanks, piping, and related facilities is required to assess the probable corrosion mechanisms affecting the facilities and to determine which structures will require CP. The materials of construction include any buried portion of the tank system (e.g., valves, fittings, tank pads, straps, anchors, foundations, ground rods, cables, monitoring devices, the tank, and the piping). The use of different metals for the various components can accelerate corrosion on an unprotected UST system and can affect the current required for CP. The existence and condition of coatings on the metallic components also have a significant influence on the design of the CP system.

4.2.3 Electrical Continuity: The design and operation of CP systems are dependent on the extent of electrical continuity of the underground metallic structures. The existence of intentional bonding, grounding, or electrical isolation of underground metallic structures should be considered. Unnecessary electrical grounds should be considered for removal. The method of electrical joining of piping, tanks, and associated underground structures, including conduits, may affect the CP design.

4.2.4 Other Underground Structures: The presence of additional underground structures unrelated to the tank system can affect the feasibility, type, and capacity of the proposed CP system.

4.2.5 Pavement: The presence and thickness of pavement at the site can affect both the operation of the CP system and the cost of installation. The location, type, age, and probable repaving schedule are of interest to the designer. The presence of other significant site improvements must be considered.

4.3 Integrity Assurance

4.3.1 The operating history of the UST system, including the date of installation and as-built drawings, provides important information for evaluation.

4.3.2 The results of tightness testing, internal inspection, or other industry recognized methods of integrity assurance should be analyzed (see API[3] RP 1631[8] for additional information).

4.3.3 The leak history of the UST may influence the feasibility of the retrofit CP system. The date, location, and type of each leak should be assessed.

4.3.4 Repairs or replacements of UST system components should be analyzed as to their effect on the system's probability for corrosion or on the operation and effectiveness of the retrofit CP system. The reason for repairs, replacements, or system modifications, as well as the materials and methods used, should be analyzed.

4.3.5 Operating data of any previous CP system for the UST, including the type of CP system (galvanic or impressed current), the date of installation, the type, size, and placement of anodes, and the level of protection, should be reviewed.

4.4 On-Site Testing

4.4.1 All test methods shall be in accordance with applicable engineering standards.

4.4.2 Soil borings may be performed. The following measurements should be recorded as each test hole boring progresses:

(a) tank-to-soil potential profile; and
(b) soil resistivity profile.

[3] American Petroleum Institute (API), 1220 L Street NW, Washington, DC 20005.

4.4.3 When required, soil samples should be extracted from the bore holes and placed in sealed sample containers for analysis to include:

(a) resistivity;
(b) pH;
(c) sulfide ion concentration;
(d) chloride ion concentration; and
(e) moisture content.

4.4.4 Tests that should be included in the investigation for the evaluation of corrosion on USTs and the design of CP systems include the following:

4.4.4.1 Soil Resistivity: Low-resistivity soils are usually more corrosive than high-resistivity soils; however, serious corrosion can also be associated with high-resistivity soils, particularly when the soil composition is not uniform. Variations in resistivity indicate variations in soil composition, which is conducive to galvanic corrosion. Accepted soil resistivity tests include the Wenner four-pin,[9] soil box, and single-probe methods.

4.4.4.2 Structure-to-Soil Potential

4.4.4.2.1 Structure-to-soil potentials are used to evaluate the corrosion activity associated with UST systems. If properly interpreted and correlated with other measurements, structure-to-soil potentials should give an indication of the severity of both galvanic and electrolytic corrosion cells.

4.4.4.2.2 Measurements should be taken with a high-input impedance voltmeter.

4.4.4.2.3 Saturated copper/copper sulfate reference electrodes (CSEs) are used for underground corrosion testing because they are stable, rugged, and yield reproducible results. Electrode placement is important when collecting the data. Proper notation of electrode location for each reading is required. When test borings are made, the reference electrode should be placed near the tank/soil interface. Typically, the test hole is drilled 0.3 m (1 ft) from the edge of the tank to a depth of 0.6 m (2 ft) below the tank. Tank-to-soil potentials are recorded at various depths to establish the potential profile from grade level to below the tank.

4.4.4.3 Stray direct current (DC) can emanate from the operation of DC transit systems, CP rectifiers, DC welding equipment, and DC motors. When discharged from the surface of a steel tank, these currents consume approximately 9 kg/A-y (20 lb/A-y) of metal. Concentrated electrolytic corrosion can cause rapid deterioration of UST systems. The presence of stray current is detected through the use of structure-to-soil potential, current flow, and potential gradient measurements.

4.4.4.4 Current requirement: Tests simulating the effects of a permanently installed CP system can be evaluated to determine the DC requirements for protection. Temporary CP anodes are installed in the surrounding soil and connected to the positive terminal of a DC power source; the negative terminal of the power source shall be connected to the UST system under test. Structure-to-soil potentials are then measured at accessible locations. Data, including the polarization effects over time, can then be extrapolated to determine the requirements for CP current. The status of electrical isolation of the structure under study is considered in the evaluation of current requirements testing.

4.4.4.5 Electrical continuity testing is necessary to determine whether all tanks and piping are electrically continuous and whether continuity with other structures exists. Temporary anodes shall be energized by a DC power source that is cycled "on" and "off." A CSE or other suitable reference electrode shall be placed in a stationary position, and structure-to-soil potentials recorded with the structure connection moved from one location to the next. At each point of structure connection, both "on" and "instant off" potential readings can be observed with the cycling of the DC power source. The CSE must remain at the same location for the duration of each continuity test. Electrical continuity is indicated when the potential measurements and changes in potential measurements with the applied current are approximately equal, regardless of the point of connection to the structure. Differences in the structure-to-soil potentials and changes in potential indicate the lack of electrical continuity between the points of contact.

4.5 Laboratory Testing

4.5.1 pH: For a given resistivity, acid soils (pH less than 7) are more conducive to ferrous corrosion. At pH values below 4, the rate of corrosion accelerates rapidly. At pH values above 10, the environment tends to passivate the steel. All pH testing should be done in accordance with ASTM[(4)] G 51.[10]

[(4)] ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

4.5.2 Chloride Ion: Chloride ions are depassivating agents and cause pitting corrosion. ASTM D 512[11] is used to measure chloride ion concentration.

4.5.3 Sulfide Ion: The presence of sulfide ions in the soil indicates anaerobic conditions. Under these conditions, sulfate-reducing bacteria can greatly accelerate the rate of corrosion. The test procedure shall satisfy the requirements of Method 4500[12] for sulfide, sulfite, and sulfate, and Method 9240 D[13] for sulfate-reducing bacteria.

4.5.4 Moisture Content

4.5.4.1 The moisture content is a significant parameter in determining the corrosiveness of a soil environment. When soil samples are collected, they shall be immediately sealed in sample containers to prevent evaporation and contamination. The moisture content of the samples should be determined using ASTM D 2216.[14]

4.5.4.2 Test borings allow for a determination of the variations in moisture content with depth. When encountered, the depth of the water table should also be noted on the boring logs.

4.6 Data Analysis

4.6.1 This subsection outlines the analysis that may be performed prior to designing a CP system to protect existing USTs. The results of tests determine the extent and type of CP system to be installed. The analysis of these data is valuable in determining unusual conditions (e.g., stray current, dissimilar metals, and large corrosion cells), native-state characteristics needed for commissioning the completed CP system, and electrical continuity.

4.6.2 Results of other tests (soil resistivity, structure-to-soil potential, stray current, current requirements, electrical continuity, pH, chloride ion, sulfide ion, moisture, etc.) aid in determining the type and extent of the CP system to be considered. Interpretation of these results should consider seasonal variations.

4.6.3 Investigation of all previous repairs to the UST shall be performed to determine the probability of severe corrosion damage to these facilities. All necessary repairs shall be completed before the installation of a CP system is considered (see API RP 1631[8] for additional information).

4.6.4 All UST systems may not be good candidates for a CP system. If tests reveal critically damaged components, consideration should be given to UST system replacement or removal from service.

Section 5: Criteria for Cathodic Protection

5.1 General

5.1.1 This section lists criteria for cathodic protection which, when complied with either separately or collectively, indicate that adequate cathodic protection of a metallic UST system has been achieved.

5.1.2 The objective of using CP is to control the corrosion of UST systems.

5.1.3 The selection of a particular criterion depends, in part, on prior experience with similar structures and environments in which the criterion has been used successfully.

5.1.4 The criteria in Paragraph 5.2 were developed through laboratory experiment or were determined empirically by evaluating data obtained from successfully operated CP systems. It is not intended that people responsible for corrosion control be limited to these criteria if it can be demonstrated by other means that the control of corrosion has been achieved.

5.1.5 Voltage measurements on UST systems are to be made with the reference electrode located on the electrolyte surface as close as possible to the UST system. Consideration must be given to voltage (IR) drops other than those across the structure/electrolyte boundary, the presence of dissimilar metals, and the influence of other structures that may interfere with valid interpretation of voltage measurements. All readings shall be taken with reference electrodes that are in contact with the electrolyte. Readings shall not be taken through concrete or asphalt. Soil contact may be established through at-grade openings, by drilling a small hole in the concrete or asphalt, or by contacting a seam of soil between concrete and asphalt.

NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

(a) Measuring or calculating the voltage drop(s).
(b) Reviewing the historical performance of the CP system.
(c) Evaluating the physical and electrical characteristics of the UST system and its environment.
(d) Determining whether or not there is physical evidence of corrosion.

5.2 Criteria for Steel Structures

5.2.1 Corrosion control can be achieved at various levels of cathodic polarization depending on the environmental condition. However, in the absence of data that demonstrate adequate CP has been achieved, one or more of the following shall apply:

5.2.1.1 A negative (cathodic) potential of at least 850 mV with the CP applied. This potential is measured with respect to a CSE contacting the electrolyte. Voltage drops other than those across the structure/electrolyte boundary must be considered for valid interpretation of this voltage measurement.

5.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a CSE.

5.2.1.3 A minimum of 100 mV of cathodic polarization. The formation or decay of polarization can be used to satisfy this criterion.

5.3 Alternative Reference Electrodes

5.3.1 Other standard reference electrodes may be substituted for the CSEs. However, their voltage measurements must be converted to the CSE equivalents as in Table 1:

Table 1: Conversion of Voltage Measurements to CSE Equivalents

	Equivalent to -0.85 V CSE	Correction
Calomel	-0.776 V	Add -0.074 V
Silver/Silver Chloride	-0.78 V	Add -0.07 V
Zinc	+0.25 V	Add -1.10 V

5.4 Special Considerations

5.4.1 Special cases, such as those involving stray currents and stray electrical gradients, that require the use of criteria different from those listed above, may exist. Measurements for current loss and gain on the structure and current tracing in the electrolyte have been useful in such cases.

5.4.2 Abnormal conditions in which protection is ineffective or only partially effective sometimes exist. Such conditions may include elevated temperatures, disbonded coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte.

5.4.3 When structures that have dissimilar metals are protected, a negative structure-to-soil potential voltage equal to that for protection of the most anodic metal should be maintained.

Section 6: Cathodic Protection Design

6.1 General

6.1.1 Information regarding the design of impressed current and galvanic anode systems can be found in NACE Standard RP0169[15] and in this standard. Information useful in the design includes:

(a) site plan and system layout;
(b) pipe, fittings, and other appurtenances;
(c) pumps and power supplies;
(d) existing and proposed CP systems;
(e) nearby buried metallic structures;
(f) site accessibility;
(g) soil conditions (e.g., resistivity, chemical composition, aeration, and moisture);
(h) electrical isolation;
(i) coating integrity;
(j) elevated temperatures;
(k) shielding;
(l) treated tank backfill material;
(m) dissimilar metals and concrete/metal interfaces; and
(n) complexing agents.

6.2 Galvanic Systems

6.2.1 This subsection describes the factors that should be considered in the design of external corrosion protection for existing UST systems using galvanic anode CP.

6.2.2 Galvanic protection systems can be applied to tank systems when the metallic surface area exposed to the soil is minimized through the application of a dielectric coating or when the surface area is small due to tank size. When current requirements are high, the use of impressed current CP should be considered to minimize the cost of the protection system (see Paragraph 6.3).

6.2.3 Electrical Isolation

6.2.3.1 Electrical isolation methods can be used to isolate the primary UST from other electrically grounded systems.

6.2.3.2 All uncoated associated piping can be electrically isolated from the tank. Submersible pumps can be isolated from the metallic piping and tank by the use of dielectric isolating unions and bushings.

6.2.3.3 Electrical isolation of the piping can be accomplished by the use of flange isolation kits, dielectric bushings, or dielectric unions rated for the proper operating pressure and compatible with the product being stored in the tank. Use of dielectric unions underground should be avoided if at all possible. Dielectric unions should remain exposed for future inspection and maintenance.

6.2.3.4 When required by local codes and regulations, the tank shall be grounded to protect against damage due to lightning. This must be accomplished without compromising the CP design.

6.2.4 Galvanic Anode Selection

6.2.4.1 The three most common types of galvanic anodes that are effective in soil environments are standard-potential magnesium (ASTM B 843,[16] **UNS**[(5)] **M11632**), high-potential magnesium (ASTM B 843, **UNS M15102**), and high-purity zinc (ASTM B 418,[17] **UNS Z13000**). The selection and use of these anodes are based on the current requirements for the structure to be protected, the soil conditions, and the temperature of the structure to be protected.

6.2.4.2 The current output from each type of anode depends greatly on the soil conditions, the anode shape, and the net driving potential of the anode.

6.2.4.3 When high-purity zinc anodes are employed, care shall be exercised to ensure the anodes meet the requirements of ASTM B 418, Type II anode material.[18] The purity of the zinc greatly affects its performance as a galvanic anode for soil applications.

6.2.4.4 Zinc anodes shall not be used when the temperature of the anode environment is above 49°C (120°F). The high temperature can cause the anode to assume passive characteristics. The presence of some chemicals in the soil, such as carbonates, bicarbonates, and nitrates, may also affect the performance of bare zinc as an anode material.

6.2.4.5 Galvanic anode performance is enhanced with special backfill material. A mixture of 75% gypsum, 20% bentonite, and 5% sodium sulfate is typically used with magnesium anodes. Either 75% gypsum, 20% bentonite, and 5% sodium sulfate or a mixture of 50% gypsum and 50% bentonite can be used with zinc anodes.

6.2.4.6 The anodes should be supplied with adequate lead wire attached. Lead wire shall be at least 4 mm^2 (#12 AWG[(6)]) solid wire with TW (thermoplastic insulated wire) or equivalent oil- and water-resistant insulation.

6.2.5 Galvanic Anode Installation

6.2.5.1 The CP anodes shall be installed around the tank in a manner that allows optimal current distribution. Anodes should be placed close to or below the elevation of the bottom of the UST. If multiple UST installations are spaced closely together, installation of additional anodes between the tanks and above the center line of the tanks may be required to provide adequate current distribution to the upper surfaces of the UST.

6.2.5.2 The anode lead wires shall be installed with sufficient slack to avoid possible damage due to settlement of surrounding soil.

6.3 Impressed Current Systems

6.3.1 This subsection recommends procedures for designing impressed current CP systems. In the design of a CP system, the following factors shall be considered:

(a) recognition of hazardous conditions prevailing at the site and selection and specification of materials and installation practices that will ensure safe installation and operation;
(b) all applicable regulatory codes;
(c) selection and specification of materials and installation practices that will ensure dependable, economical operation of the system throughout its intended operating life; and
(d) selection of proposed installation to minimize stray currents.

6.3.2 Electrical Continuity

6.3.2.1 All structures to be protected must be electrically continuous. Bonds may be required between piping and tanks and, in some cases, from tank to tank. Electrical conduits, hydraulic lifts, and utility piping, such as water and gas piping, must be investigated for isolation or continuity as required.

[(5)] Metals and Alloys in the Unified Numbering System (latest revision), a joint publication of the American Society for Testing and Materials (ASTM) and the American Society of Automotive Engineers Inc. (SAE), Warrendale, PA.
[(6)] American Wire Gauge (AWG): A particular series of specified diameters and thicknesses established as a standard in the United States and used for nonferrous sheets, rods, and wires. Also known as the Brown and Sharpe Gauge.

6.3.2.2 Nonwelded joints may not be electrically continuous. Electrical continuity between all components of the protected system must be verified.

6.3.3 Anode Systems

6.3.2.3 CP systems shall be designed to mitigate any adverse effects from stray current on foreign metallic structures within the influence of the CP system.

6.3.3.1 A variety of materials such as (a) high-silicon cast iron, (b) graphite, (c) mixed-metal-oxide-coated titanium, and (d) platinum-coated titanium or niobium are used for impressed current anodes. These anodes are normally installed with low-resistivity carbonaceous backfill.

6.3.3.2 Anode lead wires shall be constructed with insulation that meets the mechanical and chemical resistance requirements of the environment. Impressed current anodes shall be connected either singularly or in groups to the positive terminal of a DC source. The protected system components shall be connected to the negative terminal with insulated cable.

6.3.3.3 Cables between anodes, rectifiers, and negative returns from the structures to the rectifier require special insulation. It is good practice to install cables in plastic conduit. If installed in soil, the following cable insulation qualities are required:

(a) abrasion resistance;
(b) low moisture absorption; and
(c) resistance to tank product spills.

6.3.3.4 The life of impressed current anodes can be extended by the use of low-resistivity, carbonaceous, conductive backfill around the anodes. The most common of these backfill materials are metallurgical coke breeze made from coal, and calcined petroleum coke. Low-resistivity, carbonaceous, conductive backfill also reduces the anode-to-earth resistance.

6.3.3.5 Anode groundbed configurations may be vertical, horizontal, or angle drilled. The selection of anode configuration is dependent on environmental factors, current requirements, current distribution, and the size and type of structure to be protected. Caution should be exercised to ensure that anode placement results in uniform distribution of protection current to the protected system surfaces.

6.3.3.6 The current requirement for achieving a given protection criterion can be determined by preliminary testing on existing structures through the use of temporary or simulated CP systems. The current requirement can be estimated by calculating surface areas and applying a minimum protective current density based on experience and sound engineering judgment.

6.3.3.7 Although there are many sources of DC for impressed current CP, rectifiers are most commonly used. Various types of rectifiers such as (a) fixed voltage; (b) constant current; (c) automatic potential control; and (d) combinations of the above are available.

Separate terminal boxes with the DC power supply that can accommodate multiple circuit outputs that can be varied to individual circuits or anodes are available. These come equipped with shunts so that individual anode current outputs can be monitored.

6.3.3.8 All impressed current systems shall be designed with safety consideration as a priority. Caution should be exercised to ensure that all cabling is protected from physical damage and from the possibility of arcing. When required, rectifiers and junction boxes shall be explosion-proof.

6.4 Test Stations

6.4.1 Test stations for potential and current measurements should be considered for each system at sufficient locations to facilitate CP testing.

6.4.2 Test stations have a number of different configurations, including the following:

6.4.2.1 The test station can be cast iron or impact-resistant plastic but shall be set at grade in a manner to ensure its long-term durability. The test station may contain a terminal block. Wires should be color coded or otherwise permanently identified. Wire shall be installed with slack. Damage to insulation shall be avoided, and proper repairs must be made if damage occurs.

6.4.2.2 A test station can consist of a test lead continuous with the structure surface, secured by a nonconductive strap to a fixture, and accessible in the manhole opening.

6.4.2.3 If a portable reference electrode is used for monitoring, then an area of clean, unshielded backfill or soil should be made accessible in the manhole area for electrode placement.

6.4.3 Provisions should be made to monitor potentials at the bottom of tanks. Such facilities can include:

(a) permanent reference electrodes, and
(b) portable reference electrodes inserted in access tubes.

6.4.4 For galvanic anode CP systems, the test station design shall permit disconnection of the anodes to correct potential measurements for IR drop to evaluate the protection level. When desired, the test station should also accommodate test leads from buried reference electrodes.

6.4.5 The test station should be clearly marked, accessible, and installed so that it is protected from vehicular traffic.

6.4.6 All lead wires to the test station shall be protected from damage by either a minimum 0.5-m (18-in.) burial depth or a nonmetallic conduit.

6.5 Wire and Connections

6.5.1 Wire used for anode, reference electrode, and monitoring connections requires insulation with the following qualities:

(a) low moisture absorption;
(b) resistance to tank product spills;
(c) abrasion resistance; and
(d) sufficient breaking strength for the application.

6.5.2 Anode lead wires shall have the wire/anode interface connection secured by soldering or brazing. Weld-on anodes shall have a weldable steel core for connection directly to the structure. Wiring attached to the structure should be connected by exothermic weld, weldable steel pressure wire connectors, or appropriate mechanical connectors, and should be able to withstand an acceptable pull test. The area of the connection shall be cleaned by scraping or brushing prior to attachment. The connector and connection area shall be thoroughly coated after attachment.

6.6 Miscellaneous

6.6.1 Design Drawings and Specifications

6.6.1.1 Drawings shall be prepared to show the overall layout of the structures to be protected, the CP system, and associated appurtenances.

6.6.1.2 Specifications shall be prepared for all materials and installation practices that are used in construction of the CP system.

6.6.2 Spill protection, overfill protection, release detection, vapor recovery measures, and electrical grounding or internal linings should be considered in the design of the CP system for the UST system.

Section 7: Installation of Cathodic Protection Systems

7.1 General

7.1.1 All work shall be performed in accordance with all applicable health and safety regulations.

7.1.2 Notifications

7.1.2.1 Coordinating Committees in the area (such as Underground Corrosion Control Coordinating Committees [UCCCs][7]) and utility operators should be notified prior to construction and installation of the CP system(s).

7.1.2.2 Prior to excavation, public or private utility owners, as well as owners of other underground structures in the immediate vicinity, shall be notified. This provides the owners of underground structures with time to locate any structures within the proposed construction zone to avoid accidental physical damage.

7.2 Site Conditions

7.2.1 Pertinent as-built construction drawings from the UST installation shall be reviewed prior to construction. Although the location of most USTs can be determined, the location of product piping, vapor recovery lines, and vent lines can be difficult to determine. The underground structures at the facility include not only the USTs and associated piping, but also the monitoring wells and sensors, tank pit liners, and utilities that may be present.

7.2.2 Prior to installation of the CP system, certain factors such as water table, vehicular and pedestrian traffic, and aboveground structures shall be considered.

7.3 Installation Procedures

7.3.1 Although most installations do not normally disrupt operations, installation shall be coordinated with appropriate operations personnel to minimize any disruption of services. This work should also be coordinated with any other construction at the facility.

[7] The NACE International Technical Activities Division may be contacted to determine whether a UCCC is registered in the area; Call +1 281/228-6200, or e-mail tcc@mail.nace.org.

(a) design criteria;
(b) locations of CP equipment;
(c) types of test facilities;
(d) types of CP installed; and
(e) proximity of foreign structures.

7.4.2 Prior to energizing any impressed current CP system, notification shall be given to operators of nearby utilities and pipelines.

7.4.3 Prior to energizing the CP systems, data and information shall be collected to provide an initial base line of items such as:

(a) tank-to-soil potentials;
(b) pipe-to-soil potentials;
(c) dielectric isolation, if present;
(d) foreign structure-to-soil potentials;
(e) test coupons, if present; and
(f) permanent reference electrodes, if present.

7.4.4 Verification of the following details regarding CP devices and hardware shall be made prior to energizing the system:

(a) location of anodes;
(b) ratings of impressed current sources;
(c) location of test facilities; and
(d) location of CP system negatives.

7.4.5 All initial base line data shall be documented and the records maintained for the life of the system. Any deviations from the design or as-built documentation shall be noted and included with the initial base line data.

7.4.6 Current Adjustment

7.4.6.1 The exact operating level of CP systems is determined by a series of tests at various operating levels. The specific operating level depends on the criterion for CP used for the UST system (see Section 5).

7.4.6.2 When adjusting the operating levels of CP systems, it is necessary to consider stray current effects on adjacent structures such as:

(a) piping separated from the tank(s) or high-resistance fittings (e.g., threaded joints);
(b) buried electric facilities;
(c) buried fire protection piping;
(d) buried water piping;
(e) other adjacent tank systems; and
(f) municipal or utility structures serving the facility at which the tank(s) is (are) located.

7.4.7 Testing

7.4.7.1 The final operating levels of CP systems shall be established to achieve the appropriate CP criterion (see Section 5).

7.4.7.2 Documentation of all operating parameters, such as initial base line data, as-built drawings, operating currents, locations of test facilities, key monitoring locations, equipment manuals, and ground water level, shall be done after the system is energized.

7.4.7.3 All appropriate electrical parameters shall be recorded and documented for future reference.

7.5 Records

7.5.1 Tank system information shall include the following:

(a) dimension and capacity;
(b) layout of pipe system;
(c) date of installation;
(d) type of excavation and installation details;
(e) history of tank system performance and repairs;
(f) history of previous corrosion system and performance; and
(g) stored product.

7.5.2 Complete information about the design and installation of CP systems shall include:

(a) power source capacity;
(b) number and location of anodes;
(c) anode material and design life;
(d) anode installation details;
(e) type, quantity, and location of permanent reference electrodes;
(f) date of energizing and initial current and voltage;
(g) structure-to-soil potential measurements;
(h) results of continuity testing for all components listed in Paragraph 6.3.2;
(i) approved as-built drawings for final CP system design; and
(j) approved final commission report.

Section 8: Operation and Maintenance

8.1 General: This section recommends procedures and practices for maintaining continuous, effective, and efficient operation of CP systems on USTs.

8.1.1 Electrical measurements and inspection are necessary to determine that protection has been established according to applicable criteria and that each part of the CP system is operating properly.

8.1.2 Conditions that affect protection are subject to change with time. Corresponding changes may be required in the CP system to maintain protection.

8.1.3 Periodic measurements and inspections are necessary to detect changes in the CP system. Conditions in which operating experience indicates testing and inspections should be conducted more frequently than recommended in this standard may exist.

8.1.4 Care shall be exercised in selecting the location, number, and type of electrical measurements used to determine the adequacy of CP.

8.2 Maintenance Surveys

8.2.1 A survey shall be conducted after each CP system is energized to determine whether it satisfies applicable criteria (see Section 5) and operates efficiently (see Paragraph 7.4).

8.2.2 Monitoring

8.2.2.1 All corrosion control systems shall be monitored in accordance with NACE Standard TM0101[18] to assure effective operation as designed. The system shall be tested to verify its effectiveness after installation and whenever construction or maintenance in the area of the structure occurs.

8.2.2.2 Field-installed galvanic and impressed current CP systems shall be tested annually.

8.2.2.3 A factory-installed CP system shall be tested at an interval not to exceed three years if manufactured in accordance with a nationally recognized standard or code.

8.2.3 Inspection, surveys, and tests of CP systems shall be made to ensure their effectiveness and proper operation and maintenance as follows:

8.2.3.1 All sources of impressed current shall be checked at intervals not exceeding two months. Evidence of proper functioning may be current output, normal power consumption, or a signal indicating normal operation.

8.2.3.2 All impressed current CP facilities shall be inspected annually as part of a preventive maintenance program to minimize in-service failure. Inspections should include a check for electrical shorts, ground connections, meter accuracy, efficiency, and circuit resistance. The effectiveness of isolating devices and continuity bonds should be evaluated during the periodic surveys. This can be accomplished by on-site inspection or by evaluating corrosion test data.

8.2.4 Test equipment used for obtaining each electrical value shall be of an appropriate type (See Paragraph 4.4.4). Instruments and related equipment shall be maintained in good operating condition and checked annually for accuracy.

8.3 Visual Inspection: If the UST or any part of the system is uncovered, visual inspection for evidence of corrosion and coating deterioration should be made. The necessary repairs should be implemented to ensure continued corrosion protection of the UST.

8.4 Remedial measures shall be taken when periodic tests and inspections indicate that protection is no longer adequate according to applicable criteria (see Section 5). These measures may include the following:

8.4.1 Repair, replacement, or adjustment of CP system components.

8.4.2 Providing supplementary facilities when additional protection is necessary.

8.4.3 Repair, replacement, or adjustment of continuity and interference bonds.

8.4.4 Elimination of accidental metallic contact.

8.4.5 Repair of defective isolating devices.

8.5 Records

8.5.1 All records of the CP system including the following shall be maintained by the owner for the life of the system.

8.5.2 A record of surveys, inspections, and tests shall be maintained to demonstrate that applicable criteria for CP have been satisfied (see Section 5).

8.5.3 Relative to the maintenance of corrosion control facilities, the following information shall be recorded:

8.5.3.1 Maintenance of CP facilities.

8.5.3.1.1 Repair of rectifiers and other DC power sources.

8.5.3.1.2 Repair or replacement of anodes, connections, and cable.

8.5.3.2 Maintenance, repair, and replacement of coating, isolating devices, test leads, and other test facilities.

8.5.4 Records sufficient to demonstrate the evaluation of the need for and the effectiveness of corrosion control measures should be retained as long as the facility involved remains in service. Other related corrosion control records should be retained for a period that satisfies individual company needs.

References

1. NACE Standard RP0190 (latest revision), "External Protective Coatings for Joints, Fittings, and Valves on Metallic Underground or Submerged Pipelines and Piping Systems" (Houston, TX: NACE).

2. NACE Standard RP0185 (latest revision), "Extruded Polyolefin Resin Coating Systems for Underground or Submerged Pipe" (Houston, TX: NACE).

3. NACE Standard RP0375 (latest revision), "Wax Coating Systems for Underground Piping Systems" (Houston, TX: NACE).

4. NACE Standard MR0274 (latest revision), "Material Requirements for Polyolefin Cold-Applied Tapes for Underground Submerged Pipeline Coatings" (Houston, TX: NACE).

5. STI T871 (latest revision), "STI Test Procedure to Qualify a Coating for Acceptance by STI-P3 Specifications" (Lake Zurich, IL: STI).

6. UL 1746 (latest revision), "UL Standard for Safety, External Corrosion Protection Systems for Steel Underground Storage Tanks" (Northbrook, IL: UL).

7. STI-P3 (latest revision), "Specification and Manual for External Corrosion Protection of Underground Steel Storage Tanks" (Lake Zurich, IL: STI).

8. API RP 1631 (latest revision), "Interior Lining of Underground Storage Tanks" (Washington, DC: API).

9. ASTM G 57 (latest revision), "Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method" (West Conshohocken, PA: ASTM).

10. ASTM G 51 (latest revision), "Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing" (West Conshohocken, PA: ASTM).

11. ASTM D 512 (latest revision), "Standard Test Methods for Chloride Ion in Water" (West Conshohocken, PA: ASTM).

12. Method 4500, "Standard Test Method for the Examination of Water and Waste Water," in Water Quality Criteria 1972, A Report of the Committee on Water Quality Criteria (Washington, DC: National Academy of Sciences, National Academy of Engineering, 1972).

13. Method 9240 D, "Enumeration, Enrichment, and Isolation of Iron and Sulfur Bacteria," in Water Quality Criteria 1972, A Report of the Committee on Water Quality Criteria (Washington, DC: National Academy of Sciences, National Academy of Engineering, 1972).

14. ASTM D 2216 (latest revision), "Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures" (West Conshohocken, PA: ASTM).

15. NACE Standard RP0169 (latest revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE).

16. ASTM B 843 (latest revision), "Standard Specification for Magnesium Alloy Anodes for Cathodic Protection" (West Conshohocken, PA: ASTM).

17. ASTM B 418 (latest revision), "Standard Specification for Cast and Wrought Galvanic Zinc Anodes" (West Conshohocken, PA: ASTM).

18. NACE Standard TM0101 (latest revision), "Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Tank Systems" (Houston, TX: NACE).